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Abstract

Hedonic land price models often use parcel size as an explanatory variable. Empirical analyses, however, are rather ambiguous regarding the direction and the size of the effect of this variable on farmland values. The objective of this paper is to investigate this size-price relation in detail and to derive recommendations for an appropriate specification of hedonic land price models. Our analysis consists of three steps. First, we conduct a meta-analysis based on a comprehensive literature review. Second, we analyze a dataset of more than 80,000 land transactions in Saxony-Anhalt, Germany, using the non-parametric locally weighted scatterplot smoothing (LOWESS) estimator. This unconditional smoothing algorithm identifies negative size-price relations for very small and large plots, whereas it finds a positive relation for medium plot. We use this finding in our third step, a hedonic land price model, in which the size-price relation is modelled conditional on land and buyer characteristics. From these steps, we conclude that the complex relationship between land price and plot size cannot be captured by a simple functional form since it is affected by several economic factors, such as economies of size, transaction cost, and financial constraints.

Keywords: Land Prices, Parcel Size, Hedonic Model, LOWESS

JEL codes: C12, C14, Q11, Q24

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1 Introduction

Hedonic regression models are the most important workhorse for applied land price analyses. Based on the seminal work by Rosen (1974), hedonic price models relate observed land prices to land attributes and other factors that are conjectured to have an influence on land prices, such as environmental variables or population density (Huang et al. 2006). Hedonic land price models provide implicit prices for amenities, which are useful to appraise the value of a specific land plot with given characteristics or to explain regional variation in land prices (Nickerson and Zhang 2014). Moreover, hedonic regressions can be used to investigate the role of market thinness in land markets and explore the role of participants, such as farmers compared to non-farmers (Hüttel et al. 2016), as well as quantify their bargaining power (Coteleer et al. 2008; Kuethe and Bigelow 2018).

There is consensus in the literature about the direction of the impact of many land characteristics that typically enter hedonic price models, such as soil quality and distance to urban centers. This, however, is not true for another variable that is often used as a regressor in land price models: the plot or parcel size. Not only the magnitude, but even the sign of the plot size coefficient is ambiguous in various empirical studies.[1] This ambiguity of empirical findings is rooted in the complex relationship of economic factors and the price that can be measured as either a premium or as a discount for larger (or smaller) land parcels. Brorsen et al. (2015) recently provide an explanation for the “small parcel size premium”. They argue that the utility of certain types of land use, such as hobby farming or horse keeping, does not proportionally increase with parcel size beyond a specific point. They also conjecture that borrowing constraints and reduced competition – which is likely in illiquid farmland markets – may explain reduced per-hectare prices of larger parcels. At the same time, economies of size related to farm machinery and management, as well as partially fixed transaction costs in land sales may justify price premia for larger plots.

A better understanding of the impact of parcel size on land prices is important for two reasons. First, sizes of sold land plots have a huge variation, ranging from a few square meters to several thousand hectares. Thus, a single estimated coefficient for the size-price relationship that may be wrong would result in over- or underestimated values of plots with plot sizes far from the mean. Moreover, a misspecification of the size-price relationship likely leads to biased estimates of the coefficients of other model variables due to omitting relevant information. Second, from a normative perspective, it would be useful to know for land sellers if a negative price-parcel size relationship prevails on a land market. In that case, higher revenues could be generated by splitting larger plots into smaller ones.

Against this background, our first objective is to take stock of the existing empirical knowledge about the size-price relationship in agricultural land markets. To this end, we conduct a meta-analysis based on a broad survey of empirical studies that implicitly or explicitly address the size-price relationship. Our second objective is to examine several hypotheses on the size-price relationship that have been discussed in the literature using a rich data set on land

[1] Details on the ambiguity of empirical results are presented in Section 2.

transactions in Eastern Germany. We approach the latter objective in two steps. First, we explore the functional relationship between land prices and parcel size by means of a data-driven non-parametric approach. Next, we specify a parametric land price model that is able to capture the stylized size-price relation indicated by the non-parametric model. Our model specification allows for various interactions between the size variable and the moderator variables, such as the type of land. We find that there is no simple size-price-relation, neither linear nor quadratic, but that the impact of parcel size is case specific and varies with other economic parameters.

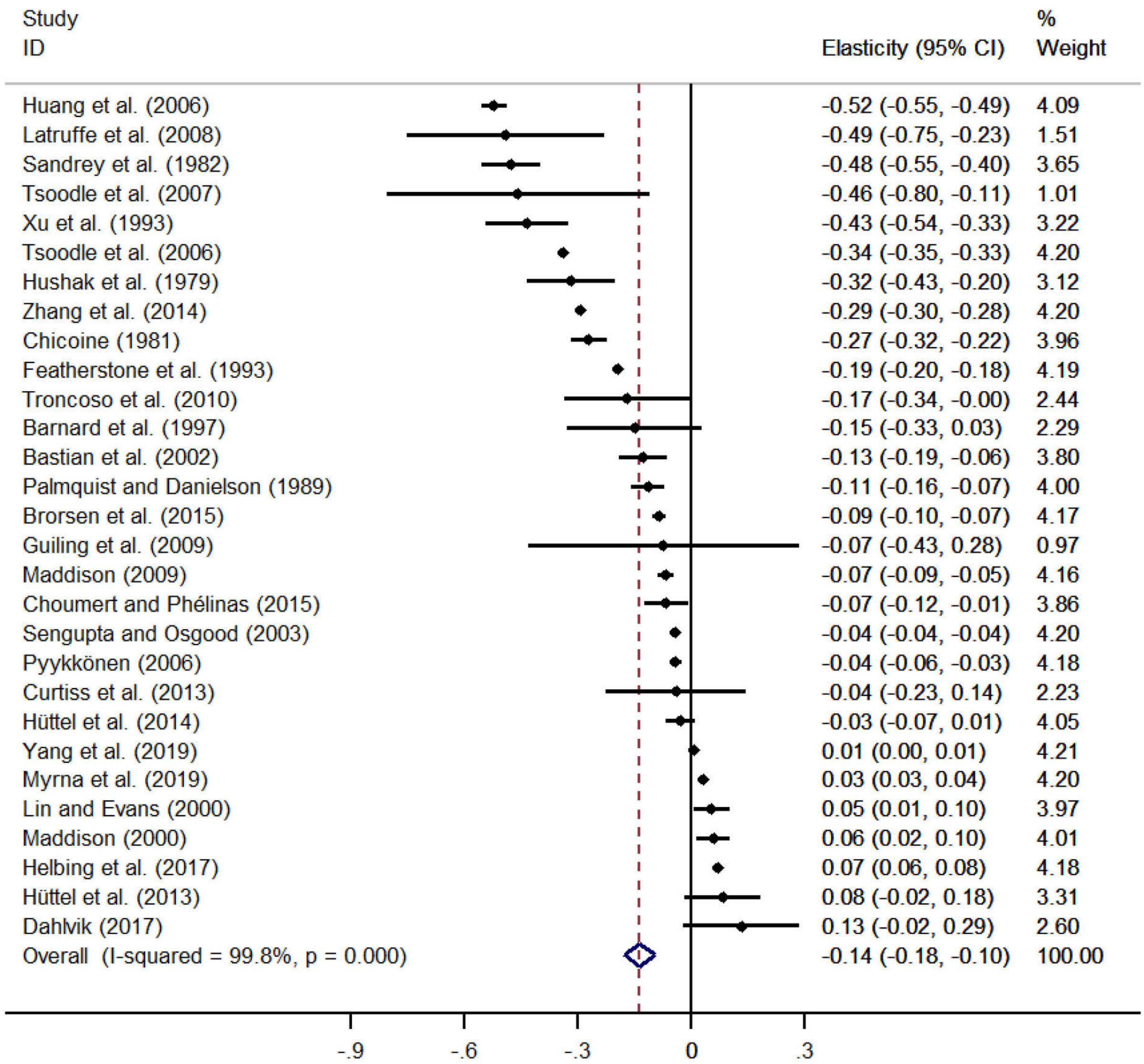
2 A Meta-Analysis of the Size-Price Relationship

Through a comprehensive literature review, we collect studies that apply hedonic regressions to explain farmland prices and include plot size as an explanatory variable. A requirement for inclusion in the meta-analysis is that the exact specification of the regression model and the estimation results, including parameter estimates and information on their reliability, have to be provided in the study. We find 29 papers published between 1981 and 2019, with the majority analyzing data from the U.S. (48%) and Europe (31%). The studies are based on very different datasets, which can be seen by the average plot size in the studies ranging from 0.11 to 584.93 ha (see Table A1 in the appendix).

The regional variation and corresponding market differences make it difficult to compare the studies. Additionally, different functional forms are applied in the models, so that the estimated coefficients cannot be directly compared. Huang et al. (2006), for example, apply a log-log model and obtain an estimated coefficient for the plot size of $\hat{\beta} = -0.54$. This means that an increase in the plot size by 1% decreases the price by 0.54%. In contrast, Yang et al. (2019), model the logarithm of the price as a function of the linear plot size ($\hat{\beta} = 0.0023$). Hence, an absolute increase of the plot size by 1 ha increases the price per ha by 0.23%. To make the results of different functional forms comparable, we convert the estimated coefficients into elasticities. Contrary to marginal effects, elasticities are dimensionless allowing comparisons across different currencies. One limitation that cannot be circumvented when comparing different functional forms, however, is the fact that the elasticities are usually not constant for varying plot size and/or price (except for the log-log model). We consider this by calculating elasticities for the average plot size and average price of the corresponding study. Hence, we obtain estimates at different points of the size-price relation, which needs to be kept in mind when interpreting the results. The alternative, evaluating all elasticities at the same point (e.g., the mean over all studies), however, would require that the results of some studies are extrapolated to a value far away from the study range for which the model was estimated. To include information on the reliability of the estimated coefficients in the meta-analysis, the standard errors of the coefficients are also converted into standard errors of the elasticities. These determine weights of the single studies when calculating the overall effect in the meta-analysis. If the standard errors of the estimated coefficients are not provided in the original paper, we derive or approximate them based on the available information, such as the t-statistic, p-value, or significance level. If several models are specified within a study, we take the median of the elasticities. If there are an even number of models, the one with a smaller standard error is chosen. Following Borenstein et al. (2011), we perform a meta-analysis with random effects since the studies were conducted independently.

The results of the meta-analysis are portrayed in a forest plot (Figure 1). The I^2 of 99.8% indicates substantial heterogeneity between studies that cannot be explained by chance (Higgins et al. 2003). The overall elasticity is -0.14, but the elasticities range from -0.52 (Huang et al. 2006) to $+0.13$ (Dahlvik 2017) and reflect the ambiguity of the results in the empirical studies. As mentioned before, we must be careful with the interpretation since the elasticities are calculated for different plot sizes. The average plot sizes for the lowest and highest elasticities are 26.30 ha and 5.50 ha, respectively. These lie in the middle range of elasticities and do not explain differences in plot size effects.

Figure 1: Results of the meta-analysis



Most articles included in the meta-analysis do not focus on the impact of the plot size variable. Nevertheless, this literature offers explicit hypotheses about the economic factors that underlie the observed size-price relationship. To begin with, why should per unit land prices vary with plot size at all? In fact, Parson (1990) argues that prices should be independent from size since arbitrage profits would otherwise be possible by splitting larger plots into smaller ones or vice versa. However, Maddison (2000) questions this “repackaging hypothesis” as it applies only to perfect markets. If transaction costs, including search and bargaining costs, are not negligible, land cannot be repackaged costlessly. In turn, one may observe varying prices for plots that are otherwise identical, but differ in size. Brorsen et al. (2015) provide an explanation for why smaller plots sell at higher prices, i.e., include a premium. Their main idea is that certain buyers acquire land for non-commercial purposes and the marginal utility of this type of land use declines rapidly with plot size and can even become zero. Examples are horse keeping for recreational purposes or "urban gardening". As this kind of land use is more frequently close to urban centers, Brorsen et al. (2015) use the distance to towns to test this hypothesis. A further example of a non-agricultural land use that generates high returns for small land plots is wind energy production (Ritter et al. 2015, Myrna et al. 2019). "Hobby farming" or wind energy production may rationalize a negative size-price relationship, but this explanation only holds for rather small land plots. In contrast, bargaining power and reduced competition among potential buyers come into play if the volume of land transactions is large. It is widely acknowledged that farmers, particularly small family farms, are financially constrained (e.g., Zinych and Odening 2009). Thus, the number of bidders who can afford to buy large land plots is naturally low. In turn, realized per hectare prices are often smaller compared to medium sized plots. Empirical evidence for the positive relationship between the number of bidders and land prices has recently been provided by Croonenbroeck et al. (2018) in the context of land auctions in Eastern Germany. On the other hand, the labor productivity of crop production decreases if land tracts are too small and fragmented (e.g., Latruffe and Piet 2014). That is, economies of size cause a positive size-price relationship and the size of this effect will clearly depend on the prevailing production technology. Another argument put forward in favor of buying a large plot instead of several smaller ones are fixed transaction costs, such as broker and notary costs, that do not vary proportionally with the plot size, but vary with price.

To summarize, several economic forces related to plot size may exist that work in the same or opposite direction. Which effect dominates depends on the particular market context. Thus, it is not surprising that the sign and the magnitude of the parcel size differs in empirical studies as shown in the meta-analysis. Another implication is that it is unlikely that the size-price relationship can be captured by a single regression coefficient in a hedonic model, at least if there is a large variation of parcel sizes in the sample. This calls for a flexible empirical approach that allows for a variable size-price relationship. We illustrate the gains of such an approach in the subsequent case study.

3 Case Study: Land Prices in Saxony-Anhalt

3.1 Study Region and Data

This case study deals with the German federal state of Saxony-Anhalt, located in Eastern Germany. As with all federal states in the former German Democratic Republic, its land market is characterized by expropriation and collectivization of land between 1949 and 1990. After the German reunification, the *Treuhandanstalt* (1990–1992) and the *Bodenverwertungs- und verwaltungs GmbH* (BVVG, since 1992) were in charge to privatize the state-owned land. The privatization process is planned to be completed by 2030.

The land market in Saxony-Anhalt experienced a strong price increase in the last decade, which is typical for East German states. Prices for agricultural land in Saxony-Anhalt more than tripled from 5,055 €/ha in 2007 to 17,903 €/ha in 2017, which lies above the average of East German states, 15,626 €/ha, but is below the average for Germany, 24,064 €/ha (Statistisches Bundesamt 2018).

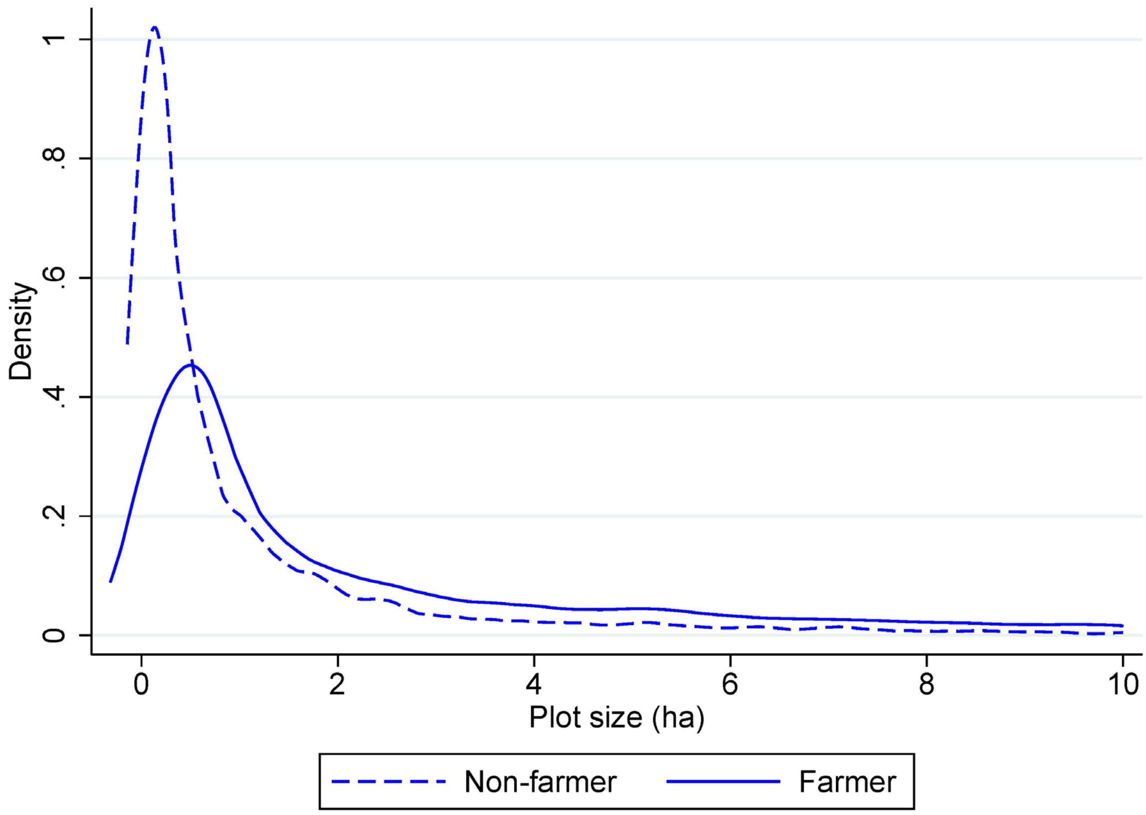
The data applied in this study were provided by the Committee of Land Valuation Experts (*Gutachterausschuss für Grundstückswerte in Sachsen-Anhalt*) and contain all transactions in Saxony-Anhalt from 1994 to 2017. In addition to the price, the size, soil quality, location, and type (arable land or grassland) of the transacted plot are included. Since 2011, information about the buyer (farmer or non-farmer) are also available.

After adjusting for missing values, documentation mistakes, and unusual circumstances, such as location in a wind farm or transactions among relatives, the dataset includes 82,650 observations. Table 1 depicts the descriptive statistics for the full sample and for the subsample since 2011, which will be used later in a separate model. The average price is 8,700 €/ha for the full period and increases to 13,219 €/ha for the subsample after 2011. The average size lies between 2 and 3 ha, but ranges between 1 m² and several hundred hectares. The average soil quality is 64 points, which corresponds to a measure of the productivity of soil at each site. The minimum soil quality value in our sample, 7, represents very low productivity, whereas the highest value, 105, represents very high productivity. The highest soil quality value obtained thus far in Germany is 120 (cf. Scheffer et al. 2010; BMJV 2007). Only 9% of the sold plots are pure grassland and 10% are sold by the BVVG. After 2011, 27% of the plots are bought by non-farmers. Interestingly, this share decreased over time from 37% in 2011 to 22% in 2017.

Table 1: Descriptive statistics

	Mean	Std. Dev.	Min	Max
Full sample (1994–2017, *N*=82,650)				
Price (€/ha)	8,700.73	12,572.69	100	958,700
Size (ha)	2.56	8.22	0.0001	557.53
Quality (index points)	63.80	22.91	7	105
Grassland (Dummy)	0.09	0.29	0	1
Seller BVVG (Dummy)	0.10	0.29	0	1
Subsample (2011–2017, *N*=21,447)				
Price (€/ha)	13,219.78	9,169.50	200	433,300
Size (ha)	2.94	8.13	0.0001	352.88
Quality (index points)	63.25	22.80	8	104
Grassland (Dummy)	0.08	0.28	0	1
Seller BVVG (Dummy)	0.11	0.31	0	1
Buyer Non-Farmer (Dummy)	0.27	0.44	0	1

Figure 2: Density functions by plot size for farmers and non-farmers (shown for plot sizes less than 10 ha)



A notable difference between farmers and non-farmers can be found in Figure 2, which depicts the kernel density of the plot size for both groups. It turns out that non-farmers generally buy smaller plots compared to farmers, namely, non-farmers have an average plot size of 1.71 ha compared to 3.40 ha for farmers. This underpins the hypothesis of different land usages and different marginal utility.

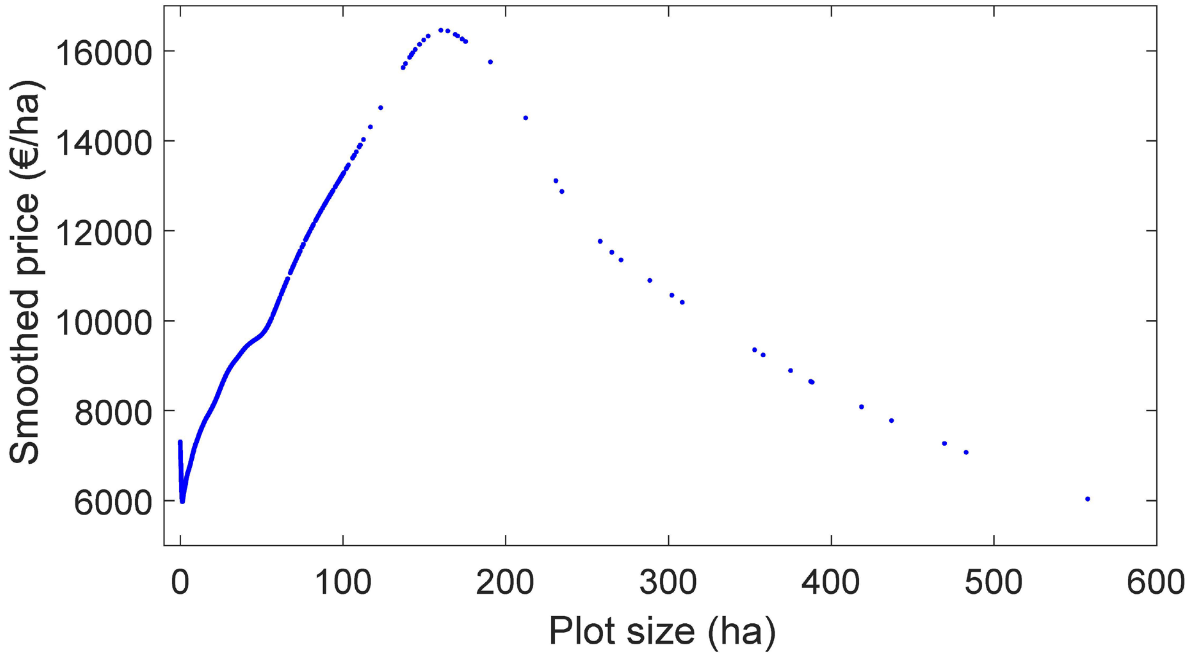
3.2 Non-Parametric Estimation

Due to the ambiguous results reported in the literature, no specific functional form is imposed *a priori* in our empirical study. To identify the appropriate specification, we proceed in two steps. First, the underlying relationship is modelled non-parametrically and unconditionally by a data-driven procedure. In a second step, a hedonic regression is specified using the functional form motivated in the first step. The hedonic models also include price determinants other than size.

Standard parametric estimation procedures can become inefficient not knowing the form of a functional relationship. One possible way to model such a relationship without assumptions about the parameterized family is a non-parametric modelling method, such as locally weighted scatterplot smoothing (LOWESS). The LOWESS method (Cleveland 1979, Cleveland and Devin 1988) follows the general idea that a complex functional relationship can be approximated by separately fitting a low-degree polynomial for each point using a small neighborhood of data. The smoothed points are estimated with weighted least-squares, weighting nearby points higher than remote ones. Each fitted value is calculated and then plotted on the scatterplot. This does not result in parameter estimates or functional equations, but rather in a visualization of the underlying functional relation.

The hyperparameters of the procedure, more precisely the degree of the polynomials and the bandwidth, have to be determined beforehand. Choosing a polynomial of degree 0 corresponds to the procedure of moving average smoothing. To better approximate the underlying functional relationship, a degree of 1, meaning a locally linear regression, can be applied. Polynomials of degree 2, meaning a locally quadratic regression which is often referred to as locally estimated scatterplot smoothing (LOESS), or higher degree-polynomials are possible; however, they tend to overfit the data and make accurate computations more difficult and complex (Cleveland 1979). Although only simple models are estimated, the procedure is computationally intensive since a separate function is estimated for each observation. The bandwidth determines the proportion of data used in each estimated polynomial, defining which data points are considered neighbors. With a lower bandwidth, the fitted curve lies closer to the specific patterns of the data points, but will have more variance left. A higher bandwidth results in a smoother curve, possibly erasing important structure.

Figure 3: Result of the LOWESS estimation



The result of the LOWESS estimation with linear polynomials and a bandwidth of 0.3 is presented in Figure 3. It depicts the smoothed price for each observation in relation to the plot size.[2] A clear non-linear shape becomes visible: Three distinct segments can be distinguished. First, we find a small parcel size premium as reported in Brorsen (2012). However, this premium applies only to very small plots below one hectare. Second, after a parcel size of

[2] To keep the results comparable, the logarithm of the price was used in the LOWESS smoothing as it will be done in the parametric estimation. For a more intuitive representation, however, Figure 3 depicts the absolute land price. The log price shows the same pattern.

about 1.3 ha, per hectare prices increase almost linearly with increasing size. Third, above plot sizes of around 160 ha, prices drop significantly until a minimum price per hectare is reached at a plot size of 558 ha. It should be noted that this segment of declining prices consists of a comparably low number of transactions. Overall, the shape of the LOWESS estimate is in line with the theoretical arguments presented in the previous section. They suggest a negative slope of the size-price regression due to non-agricultural land uses for small plots, followed by a positive slope due to economies of scale in crop production, and finally followed by a negative slope because of liquidity constraints and reduced competition among buyers.

The non-parametric estimation indicates that prices change non-linearly with respect to plot size. However, even this non-linear relation could be moderated by economic factors, such as land or buyer type. In the next section, we study the size-price relation conditional on other price determining factors through a hedonic regression.

3.3 Parametric Estimation

3.3.1 Model Specification

To assess the influence of the plot size on price, we control for other potential price-determining factors based on the available dataset as described in Section 3.1. Hence, we include soil quality in the model, as well as a dummy variable for grassland. Previous studies on the land market in Eastern Germany report that prices are considerably higher if the plot is sold by the BVVG, presumably due to a better composition or sales via public tenders (e.g., Hüttel et al. 2016). Thus, we also add a dummy variable for plots sold by the BVVG. Dummy variables are included as location classes to control for time-constant, spatial differences. The twelve classes are generated by expert committees (*Gutachterausschüsse*) by merging comparable location value zones (*Bodenrichtwertzonen).* Hence, these classes can reflect spatial heterogeneity better than rather arbitrary administrative regions, such as counties. To capture other temporal influences that are constant over space, dummy variables for each year are included. Finally, we model the logarithm of the price according to the following equation:

$$\begin{aligned}\log P_i = \beta_0 + f(A_i) + \beta_1 Q_i + \beta_2 D_{\text{grassland}} + \beta_3 D_{\text{non-farmer}} + \beta_4 D_{\text{BVVG}} \\ + \sum_{k=2}^{11} \gamma_k \, D_i^{LK} + \sum_{k=1995}^{2017} \delta_k \, D_i^{\text{Year}} + u_i,\end{aligned} \tag{1}$$

where P_i is the price per ha, $f(A_i)$ denotes a function of the plot size as specified below, Q_i is the soil quality, and $D_{\text{grassland}}$ denotes a dummy variable for grassland with arable land as the reference category. For the model using the subsample since 2011, $D_{\text{non-farmer}}$ denotes a dummy variable indicating if a farmer (0) or non-farmer (1) bought the plot. The dummy variable D_{BVVG} denotes whether the plot was sold by the BVVG (1) or not (0). D_i^{LK} and D_i^{Year} are dummy variables referring to the location class and the year of transaction, respectively. The dummy variables for the first location class and the first year of the study period are dropped and represent the reference. Finally, u_i denotes the error term.

To capture the impact of the plot size, $f(A_i)$, we use a parametric function that is more flexible compared to most previous studies. It reflects the shape we found with the unconditional LOWESS estimate and allows us to test economic hypotheses. This functional form consists of an inverse part that allows for a premium for small plots, a linear part that reflects increasing value due to economies of scale, and a quadratic part that can dampen the positive effect and turn it into a negative one (see Eq. (2)). The following inverse-linear-quadratic function has the advantage of allowing us to test the aforementioned hypotheses:[3]

Model 1:
$$f(A_i) = a_1 A_i^{-1} + a_2 A_i + a_3 A_i^2. \tag{2}$$

In Model 2, we allow the function to differ for arable land and grassland. Hence, Eq. (3) extends Eq. (2) by including interactions with the dummy variable $D_{\text{grassland}}$:

Model 2:
$$f(A_i) = (b_1 + b_2 D_{\text{grassland}}) A_i^{-1} + (b_3 + b_4 D_{\text{grassland}}) A_i + (b_5 + b_6 D_{\text{grassland}}) A_i^2. \tag{3}$$

In Model 3, we only consider observations from 2011 onwards, for which we have information about whether the buyer of the plot is a farmer. Here, the function is extended by interactions with the dummy variable $D_{\text{non-farmer}}$ (see Eq. 4)) to allow for differences in the size-price relation between these groups.

Model 3:
$$f(A_i) = (c_1 + c_2 D_{\text{grassland}} + c_3 D_{\text{non-farmer}}) A_i^{-1} + (c_4 + c_5 D_{\text{grassland}} + c_6 D_{\text{non-farmer}}) A_i + (c_7 + c_8 D_{\text{grassland}} + c_9 D_{\text{non-farmer}}) A_i^2. \tag{4}$$

3.3.2 Results

The models are estimated with ordinary least squares regression techniques with heteroscedasticity-consistent standard errors. The results in Table 2 show expected results for the classic variables: Soil quality has a positive effect in all models. An increase in soil quality by one index point leads to a 1% higher price while holding all other variables constant. Prices for grassland are, by nature, considerably lower compared to those for arable land with grassland prices being about 25% lower over the whole period and 45% lower since 2011. The BVVG as a seller achieves a price that is 28% higher for the whole period and 41% higher since 2011. This relates to the aforementioned reason of the BVVG selling at first price auctions with public tenders. Moreover, significant differences over the years are found, which reflect the strong price increase in the last decade (see Figure 4). Finally, location classes capture spatial heterogeneity of land prices.

[3] An alternative functional form capturing this pattern is a cubic polynomial as Maddison (2000) uses for the plot-size effect for farmland values in the UK.

Table 2: Estimation results

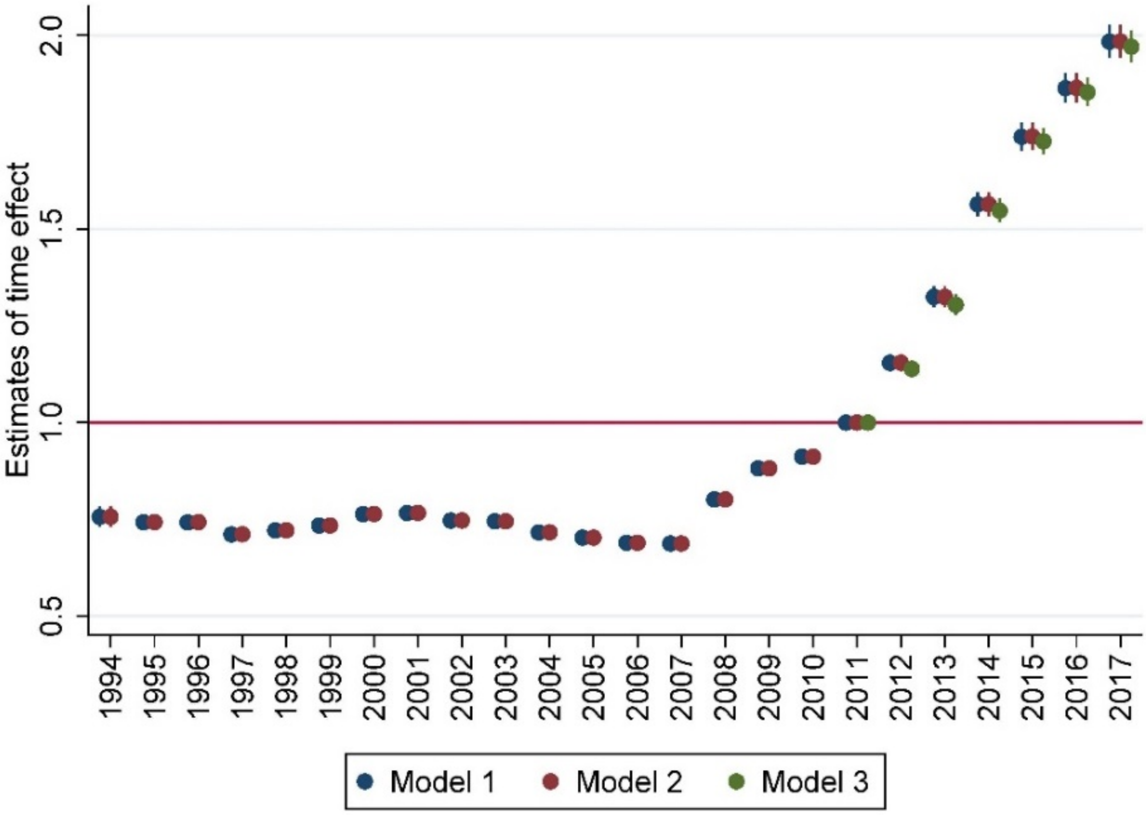
Variable	Model 1			Model 2			Model 3		
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Size (inv.)	0.000140	***	0.000019	0.000136	***	0.000019	-0.000326		0.000460
Size (inv.) x Grassland	-		-	0.000119		0.000084	0.000223		0.000144
Size (inv.) x Non-farmer	-		-	-		-	0.000331		0.000461
Size (lin.)	0.000945	***	0.000333	0.001301	***	0.000337	0.011545	***	0.001208
Size (lin.) x Grassland	-		-	-0.010528	***	0.001918	-0.009748	**	0.004934
Size (lin.) x Non-farmer	-		-	-		-	0.003864		0.002846
Size (squ.)	-0.000002		0.000001	-0.000003	**	0.000001	-0.000045	***	0.000016
Size (squ.) x Grassland	-		-	0.000070	***	0.000020	0.000003		0.000062
Size (squ.) x Non-farmer	-		-	-		-	-0.000016		0.000020
Quality	0.010541	***	0.000089	0.010538	***	0.000089	0.011983	***	0.000152
Grassland (D)	-0.272861	***	0.006524	-0.258011	***	0.007519	-0.450615	***	0.016383
BVVG (D)	0.281708	***	0.005553	0.282189	***	0.005549	0.413710	***	0.010108
Buyer Non-farmer (D)	-		-	-		-	-0.037228	***	0.008773
Constant	8.130115	***	0.037687	8.129575	***	0.037700	8.381918	***	0.044985
Time									
(see Fig. 4)									
Location									
2	0.155899	***	0.034039	0.155290	***	0.034053	0.146049	***	0.045308
3	-0.002719		0.033724	-0.003100		0.033737	-0.025492		0.044635
4	-0.053073		0.033519	-0.053088		0.033532	-0.047370		0.043979
5	-0.152984	***	0.033509	-0.153079	***	0.033522	-0.211690	***	0.044117
6	-0.170640	***	0.033467	-0.170589	***	0.033480	-0.218278	***	0.043942
7	-0.272387	***	0.033855	-0.272053	***	0.033868	-0.338655	***	0.044522
8	-0.304883	***	0.033707	-0.304629	***	0.033719	-0.453918	***	0.044443
9	-0.454644	***	0.033796	-0.454048	***	0.033809	-0.620111	***	0.044675
10	-0.438536	***	0.039934	-0.438858	***	0.039946	-0.636592	***	0.050975
11	-0.603556	***	0.036364	-0.603702	***	0.036375	-0.759984	***	0.046763
N	82,650			82,650			21,447		
R^2	0.5271			0.5273			0.6410		

Note: ** and *** denote statistical significance at the 5% and 1% significance level.

In this study, the influence of plot size variables is of particular interest. In Model 1, the inverse and the linear term have the expected positive signs and are statistically significant at the 1% level. This confirms the existence of a price premium for very small plots and a linear increase in prices for intermediate plot sizes. Table 3 reports the results of a Wald test, which clearly rejects the null hypothesis of no inverse and no quadratic term ($p < 0.0001$). Thus, the model is significantly better than modelling the influence of the plot size only linearly.

Model 2 analyzes the size-price relationship further and allows for different functions for arable land and grassland (see Eq. (3)). The results suggest the presence of a small-size premium, though this premium is different for arable land and grassland. For arable land, the linear and quadratic terms are statistically significant and have the expected positive and negative sign, respectively. These terms, however, differ considerably for grassland, which has a negative linear and a positive quadratic relation. These findings reveal that the functional form is significantly different when prices of grassland are analyzed. A Wald test rejects the null hypothesis of an equal size impact for arable land and grassland ($p < 0.0001$).

Figure 4: Estimated multiplicative time effects and confidence intervals



Note: The effects are shown as exponential of the estimated coefficients. For Models 1 and 2, they are normalized to the reference year 2011.

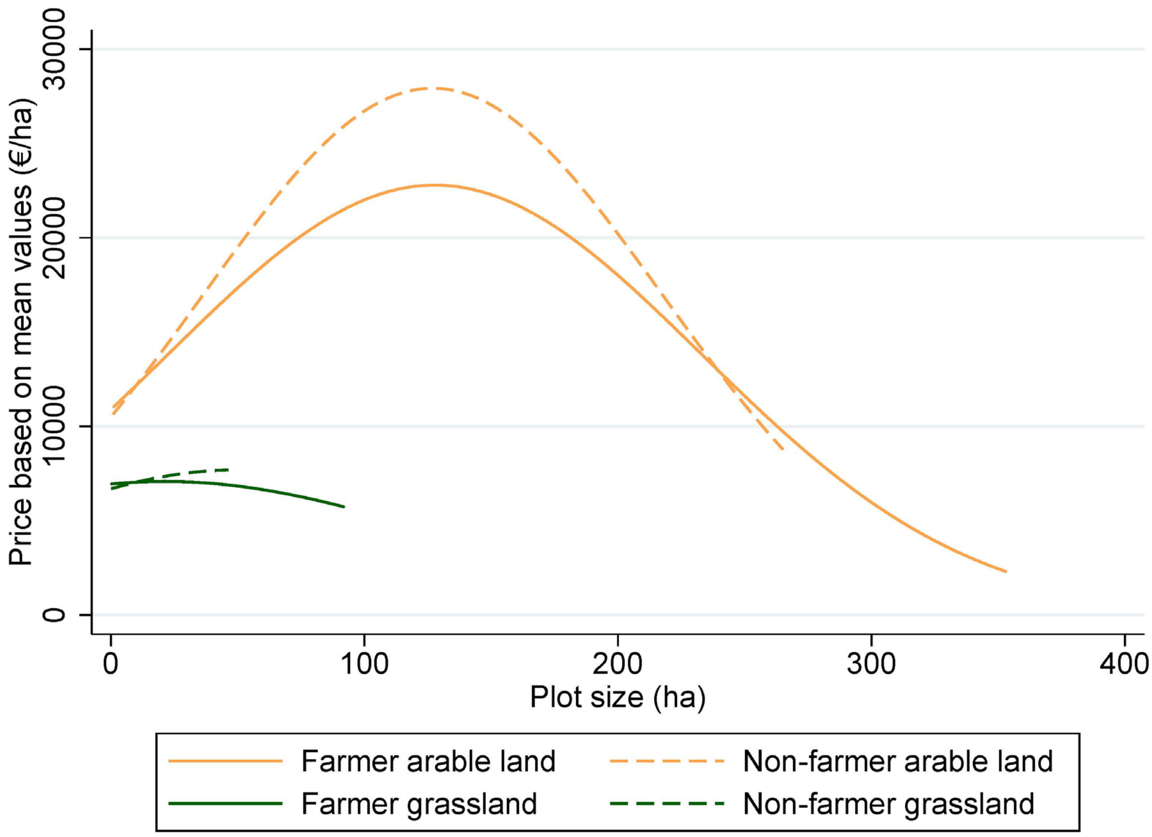
Model 3 is estimated based on the subsample of data from 2011 to 2017 since information on the buyer group is only available for this period. The results show that the inverse terms lost their statistical significance, individually and jointly ($p = 0.4125$), indicating that the small size premium has vanished in recent years. The linear and quadratic terms still play a role and the significant difference between the size-price functions for arable land and grassland remains ($p < 0.0001$). The functional forms between farmers and non-farmers do not differ significantly ($p = 0.4393$), but the dummy variable for non-farmer buyers is statistically significant and negative. Including this dummy variable in the test, the difference between farmers and non-farmers is confirmed ($p = 0.0005$).

Since plot size enters the hedonic model in a nonlinear function and via several interaction terms, it is hard to depict the overall effect of this variable. To illustrate the results of Model 3, Figure 5 portrays the average price dependent on plot size for arable land and grassland, as well as for farmers and non-farmers with the other variables held constant at their means. Note that all parameter estimates enter the calculation irrespective of their significance. It turns out that prices for arable land increase linearly for both groups until the maximum price per hectare is reached at about 130 ha. Non-farmers pay up to 5,000 €/ha more compared to farmers. After the maximum, per hectare prices decline considerably, indicating the aforementioned liquidity constraints. For grassland, where we have much lower plot sizes, there is little difference between farmers and non-farmers.

Table 3: Wald test results for the functional form of plot size

Model	Hypothesis	H_0	Test statistic	p-value
1	Linear model better	$a_1 = a_3 = 0$	$F(2, 82610) = 28.94$	$p < 0.0001$
2	No difference between arable land and grassland	$b_2 = b_4 = b_6 = 0$	$F(3, 82607) = 13.56$	$p < 0.0001$
3	No influence of size	$c_1 = \cdots = c_9 = 0$	$F(3, 21417) = 43.01$	$p < 0.0001$
	No difference between arable land and grassland	$c_2 = c_5 = c_8 = 0$	$F(3, 21417) = 26.40$	$p < 0.0001$
	No difference between farmer and non-farmer	$c_3 = c_6 = c_9 = 0$	$F(3, 21417) = 0.91$	$p = 0.4375$
	No difference between farmer and non-farmer (including level)	$\beta_3 = c_3 = c_6 = c_9 = 0$	$F(4, 21417) = 4.98$	$p = 0.0005$
	No inverse relation	$c_1 = c_2 = c_3 = 0$	$F(3, 21417) = 0.96$	$p = 0.4126$
	No linear relation	$c_4 = c_5 = c_6 = 0$	$F(3, 21417) = 41.37$	$p < 0.0001$
	No squared relation	$c_7 = c_8 = c_9 = 0$	$F(3, 21417) = 10.73$	$p < 0.0001$

Figure 5: Results of the parametric estimation (arable land vs. grassland, farmer vs. non-farmer), 2011–2017



Note: The lines are plotted for the range of the plot size in the observation period for the different groups.

4 Conclusions

In contrast to other financial assets, land is traded on illiquid markets and sales are associated with significant search and transactions costs. As a result, it cannot be expected that the price per unit of land is independent of the transaction volume. In fact, most hedonic regression models contain parcel size as an explanatory variable for the per unit price of agricultural land. A meta-analysis of 29 studies reveals that the effect of parcel size varies not only among studies, but may even change within a study. In other words, there is no simple and unambiguous size-price relationship. This is not surprising since various economic factors exist that can either cause a negative or a positive effect of plot size. Moreover, *a priori* it is not clear which factors dominate in a particular empirical context. We conclude that a simple linear or log-linear relationship, which is often assumed in empirical applications, cannot adequately capture the complex size-price relation.

In a case study based on a comprehensive data set of more than 80,000 land transactions, we identify a general pattern that consists of three different segments: a negative effect of plot size for small parcels, followed by a positive relation for medium sizes, and a negative effect for very large sizes. Accordingly, we suggest a polynomial for the plot size variable in hedonic price models, which is composed of an inverse term, a linear term, and a quadratic term. The suggestion for this functional form was based on a non-parametric LOWESS estimation that constitutes an alternative to the common Box-Cox procedure. Another insight from our analysis is that the size-price relationship may vary over time and differ for subsamples. More specifically, we find different effects of plot size for arable land and grassland, as well as for farmers and non-farmers. Two modelling strategies might cope with this complexity. One could either focus on homogeneous subsamples or include moderator variables and interaction terms that allow for variable size-price relations.

Finally, our case study reveals that unobserved heterogeneity and omitted variable bias may be an issue in hedonic land price models, as already emphasized by Nickerson and Zhang (2014). For example, we found that the BVVG sold small land plots via first price sealed bid auctions at a price premium between 2007 and 2010. This premium, however, may not solely be related to the plot size and may also be due to the competitiveness of the auction mechanism and the low search cost of this institutional seller in the market. If information about the seller is missing from the sample, this seller effect might have been erroneously interpreted as a small parcel size premium.

The results of our study have several practical implications. First, our two-step estimation approach can be applied to the estimation of locational values that are regularly conducted by valuation experts to inform land markets participants about “average” farmland values (cf. Helbing et al. 2017). For the calculation of these location values, the impact of land amenities, such as plot size, has to be explicitly considered and our analysis may serve as a guideline. Second, from a normative perspective, our findings may offer a rationale for considering multi-tract auctions to sell very large properties up to whole farms. These properties could be divided into multiple bidding units to reflect potential fragmented use. Potential purchasers could submit bids on individual tracts, combinations of tracts, and/or on the whole property. Offering property under the multi-tract auction system could attract more solvent bidders and bidders would be able to directly reveal their willingness to pay for larger non-fragmented plots.

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Appendix

Table A1: Descriptive statistics of the references used in the meta-analysis (sorted by average plot size)

Reference	Avg. plot size (ha)	Country
Lin and Evans (2000)	0.11	Taiwan
Latruffe et al. (2008)	0.60	Czech Republic
Yang et al. (2019)	2.30	Germany
Curtiss et al. (2013)	2.60	Czech Republic
Sengupta and Osgood (2003)	4.10 & 0.04[1]	USA
Myrna et al. (2019)	2.96	Germany
Hüttel et al. (2014)	5.13	Germany
Dahlvik (2017)	5.50	Finland
Hüttel et al. (2013)	6.39 & 0.67[2]	Germany
Pyykkönen (2006)	6.40	Finland
Helbing et al. (2017)	8.89	Germany
Zhang et al. (2014)	19.36	USA
Huang et al. (2006)	26.30	USA
Maddison (2009)	33.99	UK
Palmquist and Danielson (1989)	40.59	USA
Maddison (2000)	52.64	UK
Tsoodle et al. (2007)	65.56	USA
Brorsen et al. (2015)	68.80	USA
Tsoodle et al. (2006)	68.90	USA
Featherstone et al. (1993)	80.94	USA
Xu et al. (1993)	90.84 [3]	USA
Hushak et al. (1979)	90.84 [3]	USA
Chicoine (1981)	90.84 [3]	USA
Sandrey et al. (1982)	90.84 [3]	USA
Barnard et al. (1997)	90.84 [3]	USA
Guiling et al. (2009)	93.37	USA
Choumert and Phélinas (2015)	148.60	Argentina
Troncoso et al. (2010)	148.60 [3]	Chile
Bastian et al. (2002)	584.93	USA

Notes: [1] The authors divide the observations in two groups according to the plot size (smaller and larger than 0.8094 ha). [2] The authors differentiate between arable land (average plot size of 6.39 ha) and grassland (average plot size of 0.67). [3] In these articles, the average plot size is not provided, so we replace it by the continent average.